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ELF FIELD STRENGTH MEASUREMENTS MADE IN CONNECTICUT DURING 1974

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Naval Underwater Systems Center
New London, Connecticut

1 October 1975

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ELF Field Strength Measurements Made In Connecticut During 1974

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NAVAL UNDERWATER SYSTEMS CENTER
New London Laboratory

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PREFACE

The work described in this report was performed under NUSC Project No. A-690-07, "Project Sanguine Research, Development, Test, and Evaluation" (U), Principal Investigator, Dr. D. A. Miller (Code SA3B); Navy Program Element No. 11401 and Project No. X15X3, Naval Electronic Systems Command, Special Communications Project Office, Capt. W. C. Cobb (Code PME-117) Program Manager, ELF Communications Division, Capt. J. E. Galloway (Code PME-117-21), Director.

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Both 42- and 76-Hz horizontal magnetic field strength measurements were made in Connecticut during 1974. These measurements are for the purpose of further investigating sunrise, daytime, sunset, nighttime, and seasonal ELF propagation variations. The transmission source for these 1.6-Mm range measurements was the U.S. Navy ELF Wisconsin Test Facility (WTF). The principal results obtained from these measurements were (1) ELF nighttime propagation is

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much more variable than daytime propagation, (2) the "Halloween effect" was observed for the fifth year in a row, and (3) there may be as many as 80 nights each year when the average nighttime field strength will be approximately 3 dB lower than on the preceding or following nights.

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ELF FIELD STRENGTH MEASUREMENTS MADE IN CONNECTICUT DURING 1974

INTRODUCTION

Since June 1970, the Naval Underwater Systems Center (NUSC) has sporadically made farfield, extremely low frequency (ELF) horizontal magnetic field strength measurements in Connecticut.[1–4] Prior to October 1971, the local measurement site was located in the Nehantic State Forest, East Lyme, Connecticut. Presently, it is located in Hammonassett State Park, Madison, Connecticut. There are no power or telephone lines within a 1-km radius of these sites.

Measurements at 42 and 76 Hz were made in Connecticut at various times during 1974. These measurements are for the purpose of further investigating sunrise, daytime, sunset, nighttime, and seasonal ELF propagation variations. During the measurements, NUSC narrowband ELF field intensity receivers were utilized.[5] Effective integration times of 30 minutes per sample were employed. (Each 30-minute effective integration time sample is an average of three 10-minute, two 15-minute, or one 30-minute actual integration time samples.)

The transmission source for these 1.6 Mm measurements was the U.S. Navy ELF Wisconsin Test Facility (WTF). The WTF is located in the Chequamegon National Forest in north-central Wisconsin, approximately 8 km south of Clam Lake. The transmission source consists of two 22.5-km North-South (NS) antennas (one buried and one elevated) and one 22.5-km elevated East-West (EW) antenna. Each antenna is grounded at both ends. The transmission station is located at the midpoint intersection of the two antennas.

The electrical axis* of the WTF EW antenna is 114° E of N at 75 Hz and 118° E of N at 45 Hz; the electrical axis of the WTF NS antennas is 14° E of N at 75 Hz and 11° E of N at 45 Hz.[6,7] The WTF antenna array pattern can also be steered to any particular receiving location.

This report discusses the results of these latest measurements and compares them with other data taken previously.

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*Electrical axis, or electrical location, is defined as the sum of the antenna axis angle and the pattern skew angle. For instance, at 75 Hz the EW antenna axis direction is 109° E of N and the measured pattern skew is 5° clockwise; therefore, the electrical axis of this antenna at this frequency is 114° E of N.

THEORY

For distances sufficiently removed from the region of the antipode, the farfield horizontal magnetic field strength component H_ϕ produced by the WTF array (normalized with respect to the EW antenna at a current of 300 A) may be expressed as[1,8]

$$20 \log H_\phi \sim K + 20 \log E - \alpha\rho - 10 \log (a \sin \rho/a) + 20 \log \frac{F(\phi)}{B} \text{ dBA/m} \quad , \qquad (1)$$

where

K = -143.7 dB at 45 Hz and -139.3 dB at 75 Hz,

E = $\left(h_{KM} \sqrt{\sigma_{eEW}} \sqrt{c/v}\right)^{-1}$ is defined as the earth-ionosphere waveguide excitation factor; note that E is inversely proportional to the product of the effective ionospheric reflecting height h (in km) times $\sqrt{\sigma_{eEW}}$,

σ_{eEW} = effective earth conductivity beneath the WTF EW antenna = 2.8×10^{-4} mho/m at 45 Hz and 3.2×10^{-4} mho/m at 75 Hz.[8]

c/v = ratio of free space to earth ionosphere waveguide phase velocity,

α = earth-ionosphere waveguide attenuation rate (dB/Mm),

ρ = great-circle distance between WTF and receiver (Mm),

a = radius of the earth (~6.37 Mm), and

$F(\phi)/B$ = WTF array pattern factor, which equals unity in the direction of the EW antenna axis.[6,7]

JANUARY MEASUREMENTS

Transmissions at 42 Hz were received in Connecticut from 1700 to 0800 EDT during 21-26 January. Daytime, sunset transitional, and nighttime measurements were taken.

The daily sample-by-sample 42-Hz field strengths and the 80-percent confidence intervals for the pure nighttime mean data are plotted in figures 1 through 4. The 80-percent confidence interval for the pure nighttime mean data is presented to the right of the collected data points for each day. The normalized daily and monthly averages are presented in table 1. These averages are normalized with respect to the WTF EW antenna maximum value (azimuth angle = 0°), I = 300 A and f = 45 Hz.

Table 1. January 1974 Connecticut 42-Hz Field Strengths
(All data normalized to the WTF EW Antenna at 300 A and 45 Hz)

Date	Daytime H_ϕ (dBA/m)	Sunset H_ϕ (dBA/m)	Nighttime H_ϕ (dBA/m)
1/21-1/22	-148.6 ←	-151.7 ←	-150.9 ←
1/22-1/23	-145.9	-149.8	-149.2
1/23-1/24	-146.0	-149.1	-149.4
1/24-1/25	-146.0	-148.6	-149.4
1/25-1/26	-145.8	-147.4	-150.8 ←
1/9-1/10/75	------	-148.4	-149.1
1/74 AVERAGE	-146.2	-149.1	-149.9

The average January daytime field strength was the same, ±0.2 dB, as that measured in September 1970, October-November 1971, and November 1973. The average nighttime field strength was identical with that measured in December 1970 and February 1971, and approximately 1 dB lower than that measured in November 1972 and December 1973.[1,2]

Referring to figures 1 through 4, we see that the January nighttime field strengths excluding 22-23 January (figure 2) were much more variable than those measured in December 1973.[2] Note that about an hour after the Connecticut sunset and at the WTF sunset (1900), the field strengths were approximately equal to the average nighttime values.

On 21-22 January (figure 1), the daytime (1700 to 1800) field strength was approximately 3 dB lower than during the rest of this day's measurement period. The nighttime field strength displayed considerable peak-to-trough variations on the order of 5 dB. Also, the field strengths measured from 2045 to 0000 and 0200 to 0400 were approximately 2.5 dB lower than the monthly average.

During the night of 22-23 January (figure 2), the nighttime field strength was constant. It should be noted that the average nighttime signal-to-integrated-noise ratio was approximately 25 dB.

On 23-24 January (figure 3), the nighttime field strength displayed peak-to-trough variations on the order of 6 dB. The peak-to-trough variations were most noticeable between 0130 and 0730.

As shown in figure 2, between 2100 and 2200, 24 January, the nighttime peak-to-trough variation fluctuated smoothly. The field strengths recorded from 2100 to 2200 were approximately 4 dB higher than those recorded between 2300 and midnight.

On 25-26 January (figure 4), the field strength steadily declined from the daytime value of -146.3 dBA/m, reaching a minimum average value of -154.1 dBA/m around 0030, an 8-dB reduction. It remained at this level until about 0500, then gradually returned to the normal January nighttime level. Eight decibels is the largest difference between daytime and nighttime propagation conditions measured in Connecticut.

Presented in figure 5 are the sample-by-sample 42-Hz field strengths taken during the night of 9-10 January 1975. Note that the field strength measured from 1900-0000 is approximately 1 dB lower than that measured during the remainder of the night. The average nighttime field strength was about the same as that measured during the nights of 22-25 January (figures 2 through 4).

MARCH MEASUREMENTS

Transmissions at 42 Hz were received in Connecticut from 1700 to 0800 during 13-29 March. As before, daytime, sunset transitional, and nighttime measurements were takon.

The 42-Hz field strengths measured during the nights of 13-21 March are presented in figures 6 through 11. To the right of each night's data is presented the 80-percent confidence interval for the mean data of an all night path. Referring to the figures, we see that the nighttime March 42-Hz field strengths, with the exception of 19-20 March (figure 11), were similar to those measured in December 1973.[2] The measurements were not nearly as variable as those measured in January.

The average daytime field strength (table 2A) was the same, ±0.2 dB, as measured in March 1971[2], and approximately 1 dB lower than measured in December 1973[2] and January 1974. The average nighttime field strength (table 2A) was the same, ±0.1 dB, as that measured in December 1970, February 1971,[2] and January 1974, but about 1 dB lower than that measured in November 1972 and December 1973.[1,2]

On 13-14 March (figure 6), the nighttime field strength exhibited a smooth peak-to-trough variation from 0000-0400. The field strength measurements from 0000-0400 were approximately 2 dB higher than those from 2230-0000 and 0430-0600; however, the field strength rapidly increased just before sunset and during the sunrise transition period.

There was little peak-to-trough variation during the nights of 14-15, 15-16, 16-17, 18-19 March (figures 7 through 10). During the sunrise and sunset periods of 16-17 March, there were considerable peak-to-trough variations (figure 9). The variations were on the order of 3 dB.

Table 2A. March 1974 42-Hz H_ϕ Measurements
(All data normalized to the WTF EW antenna at 300 A and 45 Hz)

Date	Daytime H_ϕ (dBA/m)	Sunset H_ϕ (dBA/m)	Nighttime H_ϕ (dBA/m)	Sunrise H_ϕ (dBA/m)
3/13-3/14	-147.3	-149.1	-149.6	-148.8
3/14-3/15	-147.0	-148.0	-149.2	-148.3
3/15-3/16	-147.3	-148.7	-148.9	------
3/16-3/17	-146.7	-147.5	-149.8	-148.7
3/18-3/19	-148.3	-148.7	-150.3	------
3/19-3/20	-147.1	-148.6	-152.2 ◄	-149.8
3/20-3/21	-147.8	-148.8	-149.8	------
3/21-3/22	-147.3	-148.3	------	------
3/22-3/23	-147.4	-148.5	------	------
AVERAGE	-147.3	-148.4	-149.8	-148.9

Table 2B. March 1974 42-Hz H_ρ Measurements
(All data normalized to the elevated WTF NS Antenna at 300 A and 45 Hz)

Date	Daytime H_ρ (dBA/m)	Sunset H_ρ (dBA/m)	Nighttime H_ρ (dBA/m)	Sunrise H_ρ (dBA/m)
3/23-3/24	-149.7	-149.6	-150.7	------
3/25-3/26	-148.9	-149.6	-152.6 ◄	-151.8
3/26-3/27	-149.9	-150.8	-150.3	------
3/27-3/28	-149.4	-150.9	-150.5	------
3/28-3/29	-150.0	-149.0	-150.5	-150.3
AVERAGE	-149.6	-150.0	-150.9	-151.0

On 19-20 March (figure 11), the field strength steadily declined from the daytime value of -147.7 dBA/m until it reached a minimum average value of -153.7 dBA/m around midnight, a 6-dB reduction. The field strength from 0000 to 0530 was approximately 3.5 dB lower than the March nighttime average. The 19-20 March (figure 11) field strength versus time plot is very similar to the 25-26 January (figure 4) plot.

On 20-21 March (figure 10), a peak-to-trough variations on the order of 3 dB were observed during the sunset transition period, and during the nighttime period from 2200-0100. Only the elevated WTF NS antenna was employed for transmission from 23-29 March because of frequent fuse blowing problems at the transmitter. Consequently, instead of the normal H_ϕ component, only the abnormal H_ρ component could be received in Connecticut. The abnormal field strengths were about the same level as predicted, with the exception of a 2-dB reduction on the night of 25-26 March (table 2B and figures 12 and 13). It should be noted that the H_ρ components are normalized with respect to the elevated WTF NS antenna at 300 A and 45 Hz.

The ratio of the normalized H_ϕ component to the normalized H_ρ component may be expressed as[8]

$$\left|\frac{\text{NORM } H_\phi}{\text{NORM } H_\rho}\right| \sim \frac{k_\rho\,(c/v)}{A/B}\,, \tag{2}$$

where

$k = 2\pi/\lambda$, and λ is the free space wavelength

A/B = the ratio of the maximum field strength produced by the WTF NS antenna to that produced by the EW antenna ($A/B = 1.32$ at 45 Hz and 1.20 at 75 Hz[6,7]).

From this equation we see that the phase velocity ratio (c/v) can be determined from the measured values of H_ϕ and H_ρ. Employing the average field strength values listed in table 2B, we see that, at 42 Hz, c/v is about 1.26, 1.16, 1.10, and 1.23 for daytime, sunset transitional, nighttime, and sunrise transitional propagation periods, respectively. Note that the theoretical predictions of Bannister[4,9] and of Galejs[10] and the experimental results of Hughes-Gallenberger[11] and of Taylor-Sao[12] are highly correlated with the calculated daytime (1.26) and nighttime (1.10) values. The transitional period values lie between the daytime and nighttime values.

JULY-SEPTEMBER MEASUREMENTS

Daytime transmissions at 76 Hz were received in Connecticut during seven days in July, five days in August, and eight days in September. Nighttime transmissions, one week at 76 Hz and two weeks at 42 Hz, were received during the period of 9-29 September. The daytime daily averages are presented in table 3; the nighttime averages are listed in table 4.

The average daytime field strength measured during August and September was approximately the same as measured in 1971 and 1973.[1,2] The July average was the same as that measured in 1972 but approximately 1 dB lower than the average measurement from 1971 and 1973.

During the August daytime measurement period (figure 14), the ionosphere was quiet. This resulted in essentially constant field strengths. The ionosphere was quite active in the September and part of the July measurement period, resulting in many field strength anomalies in daytime and nighttime propagation measurements (figures 15 through 27). As usual, the daytime anomalies were much less severe and shorter lasting than the nighttime anomalies. The field strength was definitely not constant for 8 of the 15 nights measured.

On 25 July (figure 15), the daytime field strength from 1230 to 1430 was approximately 2.5 dB lower than during the rest of the day. On 26 July (figure 15), the field strength steadily declined, then steadily increased, yielding an average field strength approximately 1.5 dB higher than the previous day.

Presented in figures 16 through 18 are the September 76-Hz daytime field strength plots. The field strength was essentially constant on 10 (with the exception of one sample), 12, 20, and 23 September (figures 16 and 18). On 11, 18, 19, and 21 September (figures 16 through 18), the field strengths were variable. On 18 and 21 September (figures 17 and 18), the peak-to-trough variation was approximately 2.5 dB. The field strengths measured from 1200-1430 on 21 September (figure 18) were approximately 3 dB lower than those measured on 20 September (figure 18).

The 76-Hz sunset transitional and nighttime measurements for 9-13 September are presented in figures 19 and 20. (Night began at approximately 2130.) On 9 September (figure 19), the field strength from 2130 to 2330 was approximately 1 dB higher than from 2330-0230. The field strength on 10 September (figure 19) increased by approximately 1 dB around 2230, steadily decreased approximately 5 dB by 0045, then increased again. On 11 September (figure 19), the field strength gradually decreased by approximately 4.5 dB from 2100 to 0230.

On 12 September (figure 20), the nighttime field strength was constant. The transitional period field strength on 13 September (figure 20) behaved normally until approximately 2000. At 2000 it decreased by approximately 1.5 dB and then began increasing at 2130 until it ceased its climb of 5 dB at 2200. The nighttime field strength then rapdily decreased until approximately midnight, reaching an

Table 3. July-September 1974 Connecticut Daytime 76-Hz Field Strengths
(All data normalized to the WTF EW Antenna at 300 A and 75 Hz)

July	H_ϕ (dBA/m)	August	H_ϕ (dBA/m)	September	H_ϕ (dBA/m)
18	-144.5	4	-143.7	10	-144.0
22	-144.5	6	-143.7	11	-143.9
23	-145.3	7	-143.8	12	-143.7
25	-145.7 ←	14	-143.8	18	-144.7 ←
26	-144.3 ←	19	-143.5	19	-143.7
30	-144.8			20	-143.2 ←
31	-144.9			21	-145.1 ←
				23	-143.8
AVERAGE	-144.8		-143.7		-144.0

Table 4. September 1974 Connecticut Nighttime 42- and 76-Hz Field Strengths
(All data normalized to the WTF EW Antenna at 45 or 75 Hz)

Frequency (Hz)	Date	Sunset H_ϕ (dBA/m)	Night H_ϕ (dBA/m)	Frequency (Hz)	Date	Sunset H_ϕ (dBA/m)	Night H_ϕ (dBA/m)
76	9/9	-145.5	-145.6	42	9/18	-148.1	-149.2
76	9/10	-145.3	-145.6	42	9/19	-147.8	-150.3 ←
76	9/11	-145.5	-147.0 ←	42	9/20	-148.7	-149.6
76	9/12	-145.2	-145.8	42	9/21	------	-152.5 ←
76	9/13	-146.3	-147.3 ←	42	9/23	-147.9	-149.5
				42	9/24	-148.6	-149.4
				42	9/25	-147.8	-150.3 ←
				42	9/26	-147.9	-150.9 ←
				42	9/27	-148.7	-149.3
				42	9/28	-148.2	-152.2 ←
AVERAGE		-145.5	-146.2	AVERAGE		-148.2	-150.2

average level approximately 7 dB lower than the 2200 level. It should be pointed out that the -141.9 dBA/m field-strength point at 2145 (figure 27) is not an aberration. It is an average of two 15-minute samples with magnitudes of approximately -139.9 (the highest level ever measured in Connecticut, day or night) and -144.4.

The 42-Hz sunset transitional and nighttime field strength plots for 18-21, 23-28 September are presented in figures 21 through 25. (Night began at approximately 2100.) On 18 September (figure 21), the nighttime field strength gradually declined approximately 2 dB during the night. The field strength, on 19 September, steadily declined approximately 5 dB from 2100 to 0400 (figure 21).

On 20 September (figure 22), the field strength was essentially constant. During the following night, 21 September (figure 22), the field strength from 2130 to 0018 was approximately 3 dB lower than from 0018 to 0400. From 0018 to 0400, the field strength was approximately 2 dB lower than the field strengths of 18, 19, 20 September.

On 23 September (figure 23), the nighttime variation was small, with a peak-to-trough variation of approximately 2 dB. The peak-to-peak variation on 24 September increased to approximately 4 dB.

The field strength steadily declined on both 25 and 26 September (figure 24), reaching a minimum at 2324 on the 25th and 0030 on the 26th, then steadily increased again. The peak-to-trough variation was approximately 3 dB on 25 September and approximately 5 dB on 26 September.

Nighttime field strength on 27 and 28 September (figure 25) was constant. (Nighttime began at approximately 2100.) The average field strength on 28 September was 3 dB lower than the average on 27 September.

Daytime transmissions of 42 Hz were also monitored on 24 September (figure 26) and 25 September (figure 27). The variations in the nighttime data have already been discussed. Daytime field strength on 24 September was constant. On 25 September, the daytime field strength was approximately 1 dB higher than on 24 September, with peak-to-trough variations of approximately 3 dB.

As mentioned before, the ionosphere during the September measurement period was unusually active compared with the ionospheric activity of previous measurement periods. There were several solar flares, magnetic storms, and a minor PCA* event. There now seems to be little doubt that ELF field strength anomalies are caused by ionospheric irregularities.

---

*Polar Cap Adsorption

OCTOBER MEASUREMENTS

Transmissions at 76 Hz were received in Connecticut from 28 October to 1 November. Measurements took place between 1000 and 0100. Daytime, sunset transitional, and nighttime measurements were taken.

The October measurement period is highlighted by the "Halloween effect." First observed in 1970, between 28 and 31 October, the effect is marked by an average drop in field strength of 2 to 5 dB, relative to the preceding and following nights.[1,2] The effect has been observed in both the 40- to 50- and 70-to 80-Hz frequency bands. The 76-Hz field strengths measured during this period are presented in figures 28 through 33. Located to the right of each night's data is the 80-percent confidence interval for the data of an all-night path.

The average daytime field strength (table 5) was about the same as measured in October 1971, 1973[1,2] and in August and September 1974. It is approximately 1 dB higher than measured in October 1972[1] and July 1974. The average nighttime field strength (table 5) was approximately 0.5 dB lower than measured in October 1973,[2] approximately 1.5 dB higher than measured in October 1972,[1] and approximately 1.5 dB lower than measured in October 1971.[1]

On both 28 and 29 October (figures 28 and 29), the field strength increased by approximately 1 dB over the nighttime measurement period.

Table 5. October 1974 Connecticut 76-Hz Field Strengths
(All data normalized to the WTF EW Antenna at 300 A and 75 Hz)

Date	Daytime H_ϕ (dBA/m)	Sunset H_ϕ (dBA/m)	Nighttime H_ϕ (dBA/m)
10/8	-144.2	------	------
10/28	-144.0	-144.3	-145.3
10/29	-144.1	-143.8	-145.3
10/30	-143.9	-144.6	-147.3 ←
10/31	-145.2 ←	-146.2 ←	-147.7 ←
11/1	-144.0	-144.3	-146.5
AVERAGE	-144.2	-144.6	-146.4

During 30 October (figure 30), the daytime field strength was the same as that measured on 28 and 29 October. Beginning at 1800 (during the sunset transition period), the field strength started a series of fluctuations that continued until 2300. The fluctuations followed this pattern: 1800 to 1930, rapid decrease of 5 dB; 1930 to 2100, steady increase of 3 dB; 2100 to 2300, steady decrease of 3 dB. The nighttime average field strength of 30 October was approximately 2 dB lower than the average of 28 and 29 October.

The daytime field strengths on 31 October (figure 31) were 1 dB lower than those measured on 28, 29, 30 October. The field strength steadily declined during the sunset transitional period, reaching a minimum at 2030. The nighttime field strength then steadily increased approximately 3 dB during the rest of the nighttime measurement period. The nighttime average field strength was approximately 0.5 dB lower than the nighttime average of 28, 29, 30 October and 2.5 dB lower than the nighttime average of 28, 29 October.

On 1 November (figure 32), the daytime field strength returned to its normal level. The nighttime field strength (although essentially constant) was about 1 dB below the level measured during 28, 29 October.

The nighttime field strengths measured during this Halloween period are presented in figure 33. As mentioned before, the field strengths measured on 30 and 31 October were 2 to 2.5 dB lower than measured on 28 and 29 October, and 1 dB lower than measured on 1 November. This is the fifth year in a row that the "Halloween effect," one or more low field strength nights between 28 and 31 October, has been observed!

DISCUSSION

The 42- and 76-Hz Connecticut measurements in 1974 have again demonstrated that the short-term sample-to-sample variability of ELF nighttime propagation is much greater than the short-term sample-to-sample variability of ELF daytime propagation.

Presented in table 6 are the ratios of the number of low field strength nights to total nights measured in Connecticut from 1970-74. During the 1974 measurement period, there were 13 nights out of the 37 measured when the average nighttime field strength (measured during at least a 4-hour period) was approximately 3 dB lower than on preceding or following nights. In total, there have been 30 nights of the 140 measured when the average nighttime field strength (measured during at least a 4-hour period) was 2 to 6 dB lower than during the preceding or following nights. If these results are extrapolated to a year, there may be as many as 80 nights each year when the average nighttime field strength would be approximately 3 dB lower than on preceding or following nights. Nighttime field strength reduction, also observed at other mid-latitude measurement locations,[13,14] appears to be due primarily to a decrease in the nighttime excitation factor rather than to an increase in the nighttime attenuation rate. This follows from the fact that, at a range of 1.6 Mm (Connecticut), a 0.4 dB/Mm change in attenuation rate is only a 0.6-dB change in field strength.

Table 6. Number of Low Field Strength Nights Measured in Connecticut, 1970-74

Year	45-Hz Band	75-Hz Band	Overall
1970	4/17	1/2	5/19
1971	2/12	0/13	2/25
1972	0/5	1/5	1/10
1973	2/8	7/41	9/49
1974	9/27	4/10	13/37
TOTALS	17/69	13/71	30/140

It has been hypothesized [15,16,17] that these lower mid-latitude nighttime field strengths are a result of charged particles dumped from the outer radiation belt following their insertion into the trapping zone during the early stages of magnetic storms. In many cases, there is a definite correlation between ionospheric irregularities and the lower-than-normal measured nighttime field strengths[14,15,16]. In other cases, however, little correlation exists.

Presented in table 7 are the 1970-74 Connecticut normalized monthly averages. All the results are normalized to the WTF EW antenna at 300 A and 45 or 75 Hz. From this table, we see that, at 45 Hz, the average daytime field strength is -146.9 dBA/m, and the average nighttime field strength is -149.2 dBA/m. At 75 Hz, the average daytime field strength is -144.0 dBA/m, and the average nighttime field strength is -145.8 dBA/m.

One of the main conclusions of reference 9 was that the attenuation rate α was directly proportional to the excitation factor E. (At 75 Hz, α is approximately 1.4 E dB/Mm. At 45 Hz, α is approximately 0.9 to 1.0 E dB/Mm.) Since α is directly proportional to E, field strength measurements could be taken at just one site in order to determine average values of both α and E for a particular measurement period.

From figure 34 (Connecticut normalized field strengths versus excitation factor) and table 7 (1970-74 Connecticut monthly averages), we see that, at 45 Hz

$$E_D \sim 1.03$$

$$E_N \sim 0.75$$

$$E_D/E_N \sim 1.37$$

$$\alpha_D \sim 0.93 \text{ dB/Mm}$$

$$\alpha_N \sim 0.75 \text{ dB/Mm}$$

Table 7A. 1970-74 Connecticut Monthly Averages at 45 Hz
(All data normalized to the WTF EW Antenna at 300 A)

Daytime			Nighttime		
Month	Monthly Average (dBA/m)	Number of Measurement Days	Month	Monthly Average (dBA/m)	Number of Measurement Days
9/70	-146.0	3	9/70	-147.8	3
10/70	-148.0	2	10/70	-149.4	3
11/70	-149.0	3	11/70	-149.5	3
2/71	-148.0	6	12/70	-149.8	8
3/71	-147.1	3	2/71	-149.9	3
10/71	-146.0	7	10/71	-147.1	9
11/71	-145.9	4	11/72	-149.1	5
11/72	-148.3	1	12/73	-148.9	8
12/72	-148.5	1	1/74	-149.9	5
11/73	-146.0	2	3/74	-149.8	7
1/74	-146.2	5	9/74	-150.2	10
3/74	-147.3	9	1/75	-149.1	1
9/74	-146.9	2			
AVERAGE	-146.9	48	AVERAGE	-149.2	63

Table 7B. 1970-74 Connecticut Monthly Averages at 75 Hz
(All data normalized to the WTF EW Antenna at 300 A)

Daytime			Nighttime		
Month	Monthly Average (dBA/m)	Number of Measurement Days	Month	Monthly Average (dBA/m)	Number of Measurement Days
6/70	-143.9	2	11/70	-147.0	2
9/70	-143.6	4	1/71	-145.4	2
10/70	-143.8	4	10/71	-144.8	11
1/71	-143.8	4	10/72	-147.9	2
10/71	-144.0	10	11/72	-147.1	3
3/72	-144.8	2	3/73	-145.5	3
7/72	-144.8	7	4/73	-145.9	10
11/72	-145.1	2	5/73	-146.7	6
12/72	-145.1	3	9/73	-145.6	6
4/73	-144.1	5	10/73	-145.8	8
5/73	-144.2	5	11/73	-146.0	8
9/73	-144.2	6	9/74	-146.1	5
10/73	-144.0	2	10/74	-146.4	5
11/73	-143.9	5			
7/74	-144.8	7			
8/74	-143.7	5			
9/74	-144.0	8			
10/74	-144.2	6			
AVERAGE	-144.0	87	AVERAGE	-145.8	71

These are almost the same as the average 45-Hz values determined from various propagation paths (table 1 of reference 9). At 75 Hz,

$$E_D \sim 0.91$$

$$E_N \sim 0.7$$

$$E_D/E_N \sim 1.30$$

$$\alpha_D \sim 1.27 \text{ dB/Mm}$$

$$\alpha_N \sim 0.98 \text{ dB/Mm.}$$

These are almost identical to the 78-Hz values determined over the 4900-km path from North Carolina to Iceland (see reference 18 and table 1 of reference 9).

Once α and E are determined for a particular site, field strengths can be predicted at other distant sites[9]. As an example of the accuracy this prediction method yields, the predicted and measured Norway results (J. R. Davis, NRL, personal communication, 1975) for four different time periods are presented in table 8. Note that the Norway predicuons are based upon simultaneous field strength measurements taken in Connecticut.

Table 8. Predicted Versus Measured Norway Field Strengths

Date	Predicted α (dB/Mm)	Predicted E	Predicted H Field (dBA/m)	Measured H Field (dBA/m)
Jan 74	0.72	0.72	-156.0 ± 0.5	-155.7
Mar 74	0.70	0.70	-156.2 ± 0.5	-156.5
Sep 74	0.66	0.66	-156.5 ± 0.5	-156.7
Jan 75	0.76	0.76	-155.9 ± 1.5*	-157.2

*This prediction (Jan 75) is based upon only one night's worth of Connecticut measurements.

CONCLUSIONS

The horizontal magnetic field strengths taken in Connecticut during 1974 have again demonstrated that the short-term sample-to-sample variability of ELF nighttime propagation is much greater than the short-term sample-to-sample variability of ELF daytime propagation.

In addition, there have been 13 nights out of the 37 measured when the average nighttime field strength (measured during at least a 4-hour period) was approximately 3 dB lower than on a preceding or a following night. During the entire 1970-74 period, there were 30 nights out of the 140 measured when the average nighttime field strength (measured during at least a 4-hour period) was 2 to 6 dB lower than during the preceding or following nights. In particular, this phenomenon has occurred between 28 and 31 October for the past five years. If these results are extrapolated to an entire year, there may be as many as 80 nights a year when the average nighttime field strengths would be approximately 3 dB lower than on preceding or following nights. Further investigations of this phenomenon are in progress.

Although the evidence is still inconclusive, the low nighttime field strengths appear to be a mid latitude effect. Given that they are a mid-latitude effect, then a mid-latitude ELF transmitting antenna system may not perform as well as one located at a different, more favorable latitude. One way to determine if these low field strength nights are a mid-latitude effect would be to simultaneously measure at a 300- to 400-km nearfield site (e.g., northern Wisconsin or Michigan) and two distant far-field sites (e.g., Connecticut and Norway). Such an experimental program is planned for FY 1976.

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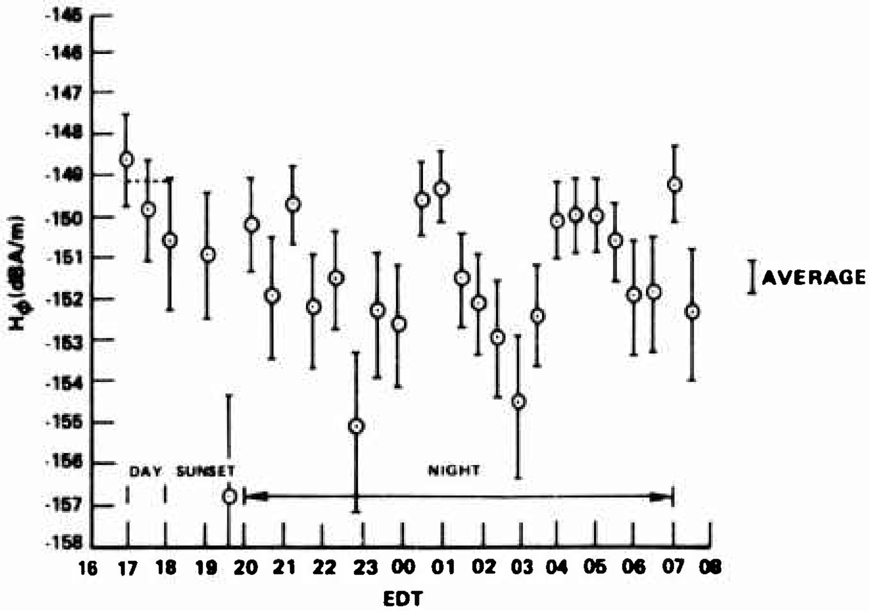

Figure 1. 21-22 January 42-Hz Field Strengths Versus Local Time

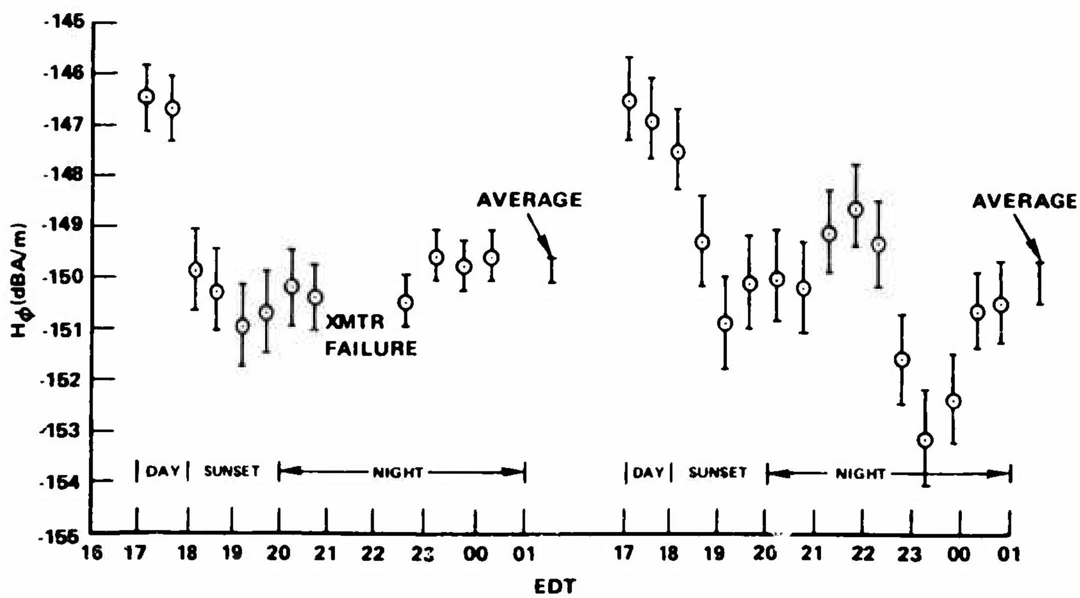

Figure 2. 22-23 and 24-25 January 42-Hz Field Strengths Versus Local Time

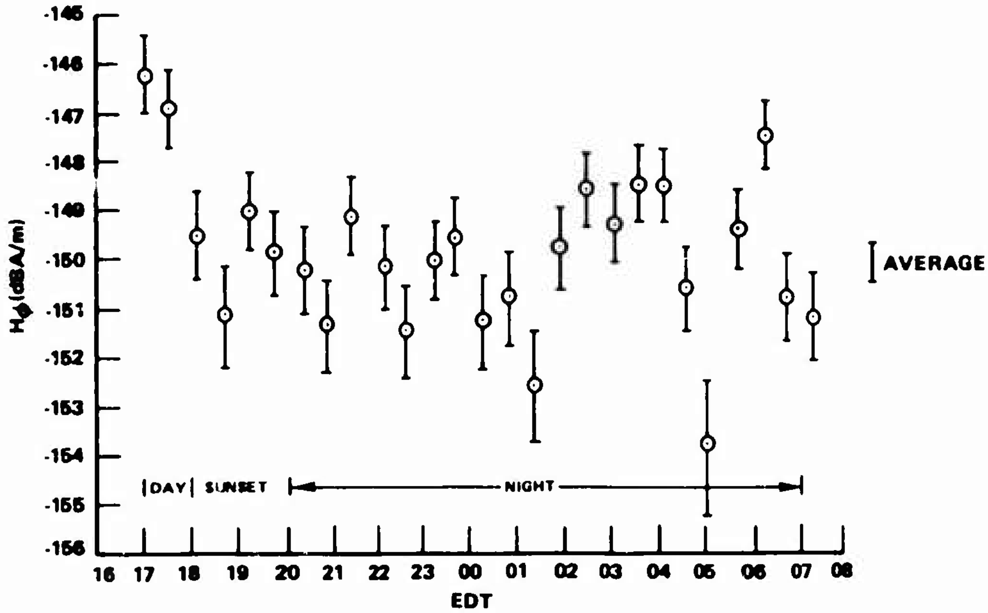

Figure 3. 23-24 January 42-Hz Field Strengths Versus Local Time

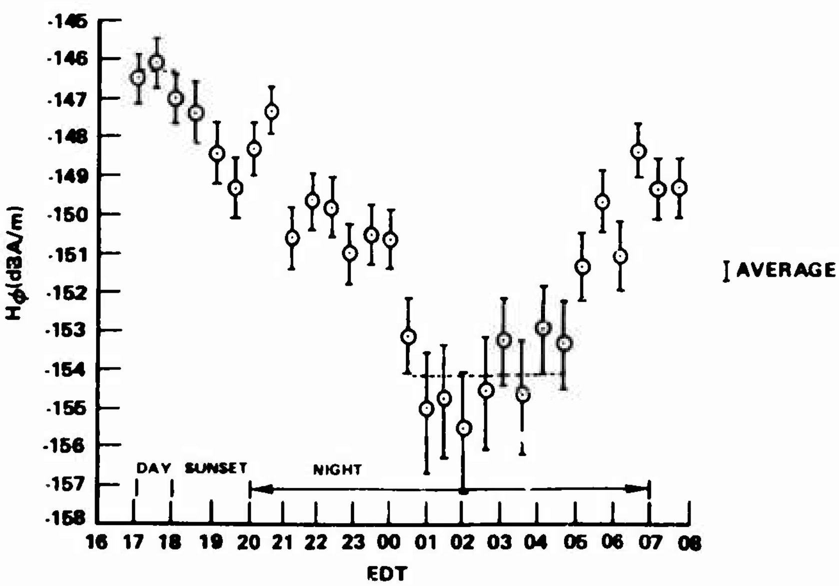

Figure 4. 25-26 January 42-Hz Field Strengths Versus Local Time

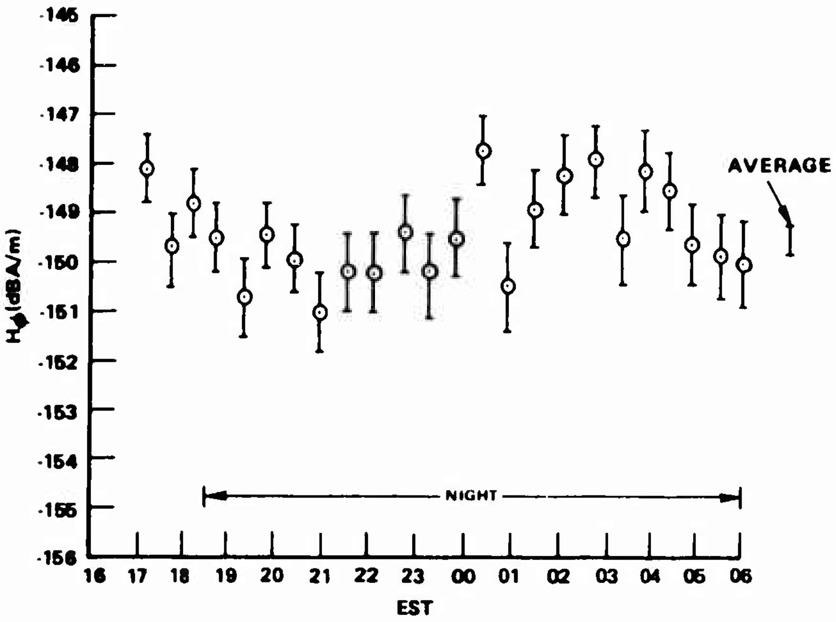

Figure 5. 9-10 January 1975 42-Hz Field Strengths Versus Local Time

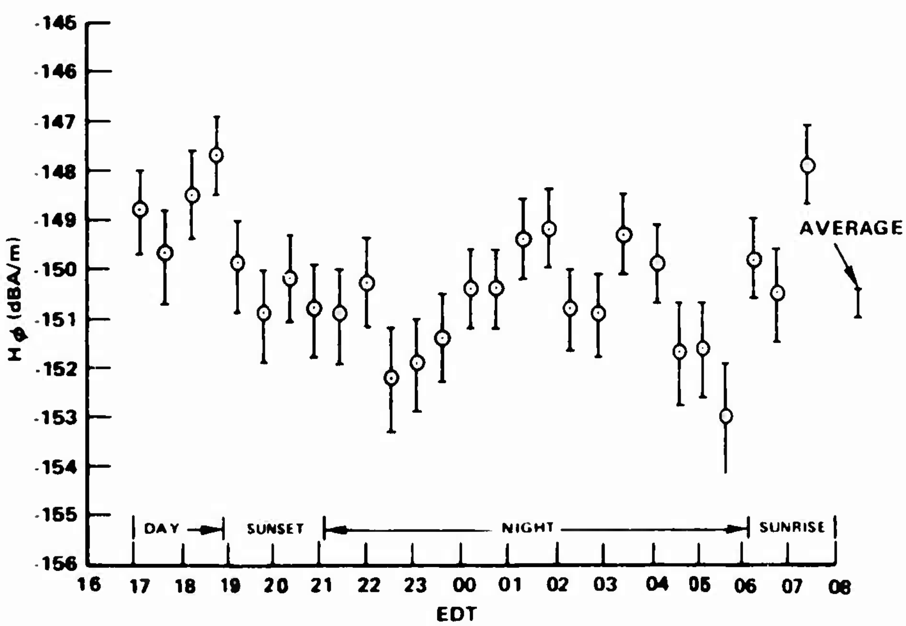

Figure 6. 13-14 March 42-Hz Field Strengths Versus Local Time

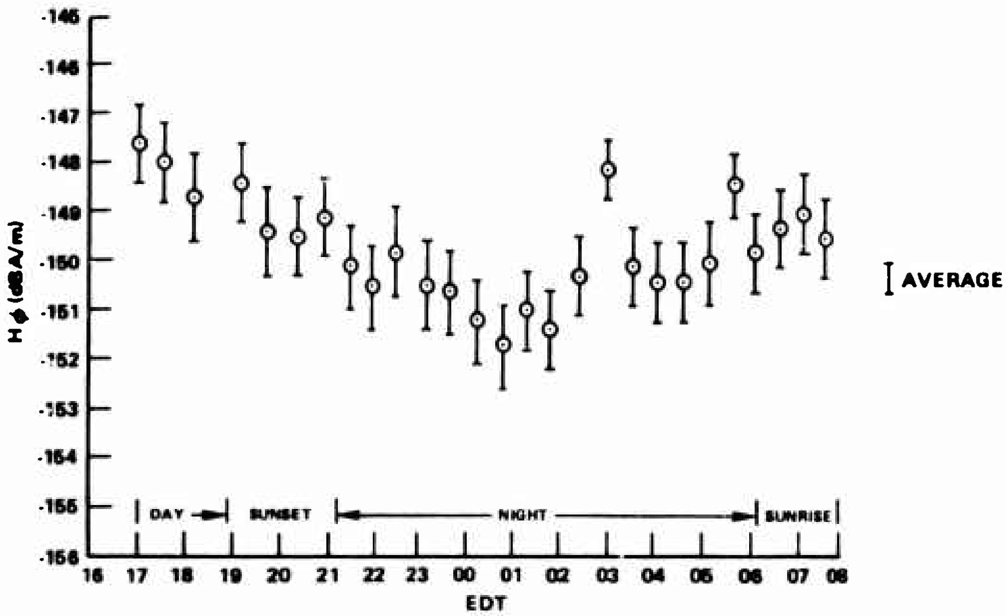

Figure 7. 14-15 March 42-Hz Field Strengths Versus Local Time

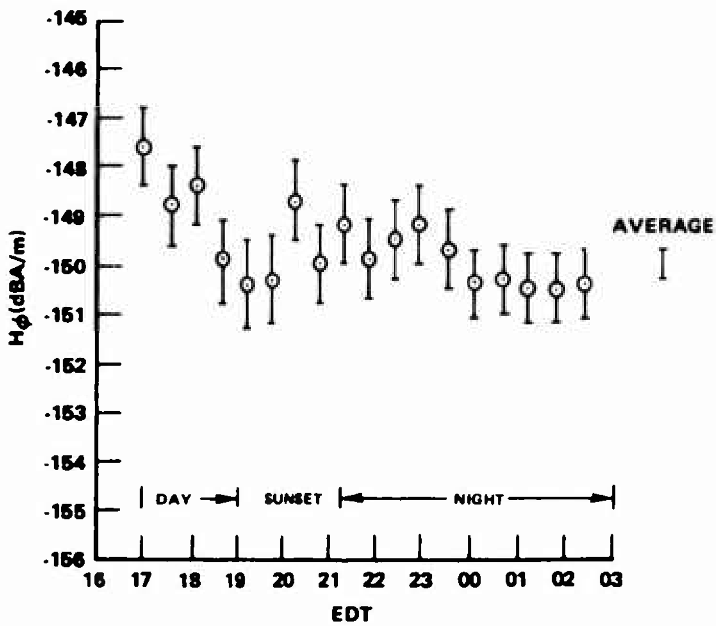

Figure 8. 15-16 March 42-Hz Field Strengths Versus Local Time

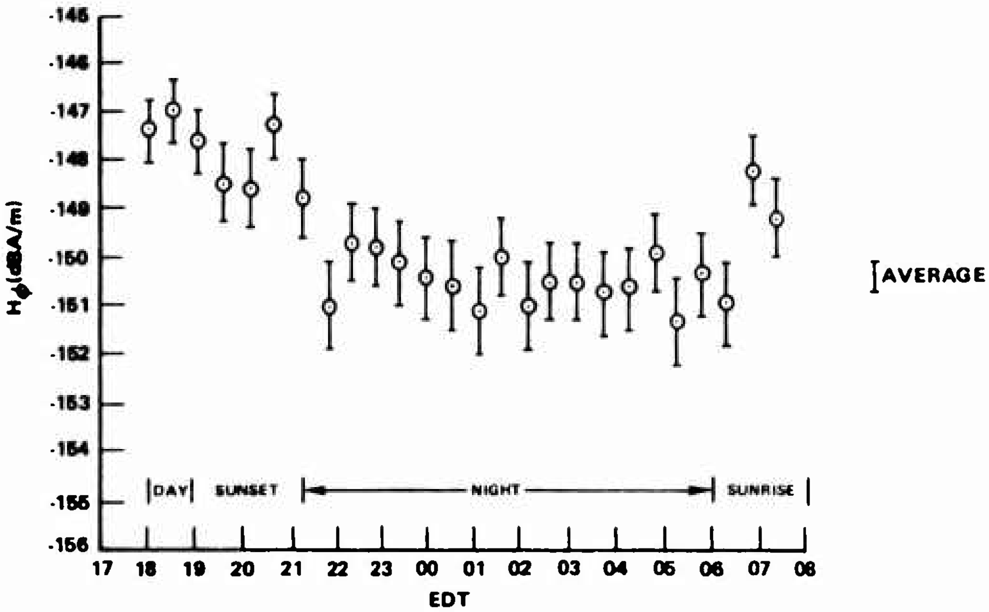

Figure 9. 18-19 March 42-Hz Field Strengths Versus Local Time

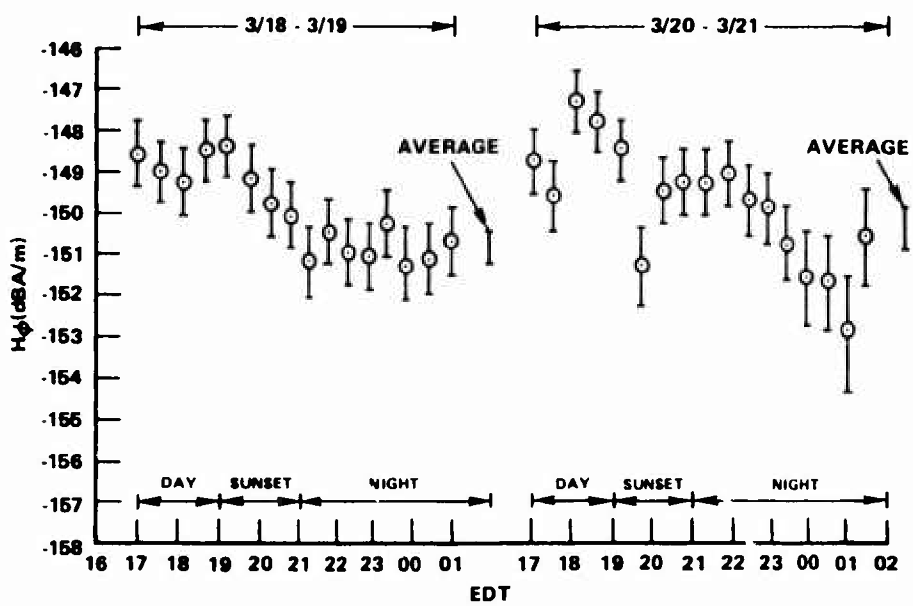

Figure 10. 18-19 and 20-21 March 42-Hz Field Strengths Versus Local Time

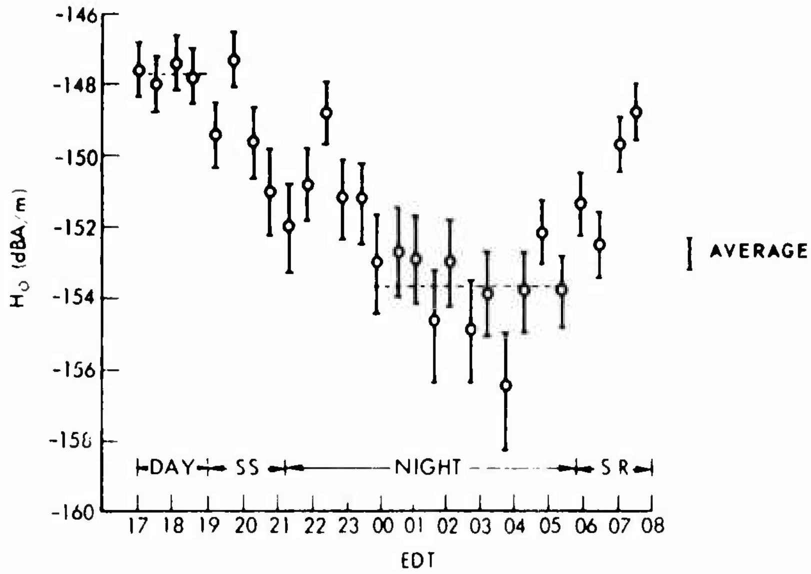

Figure 11. 19-20 March 42-Hz Field Strengths Versus Local Time

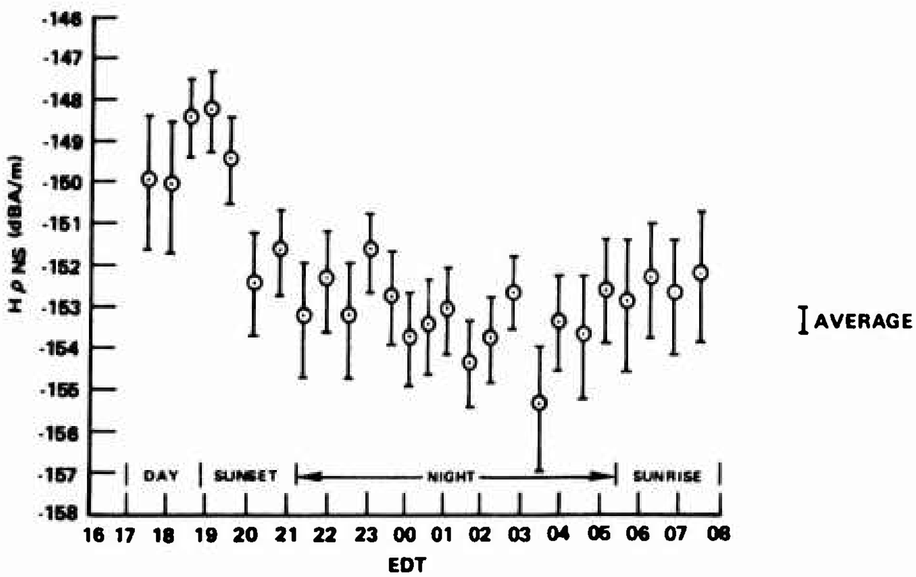

Figure 12. 25-26 March 42-Hz H_ρ Field Strengths Versus Local Time

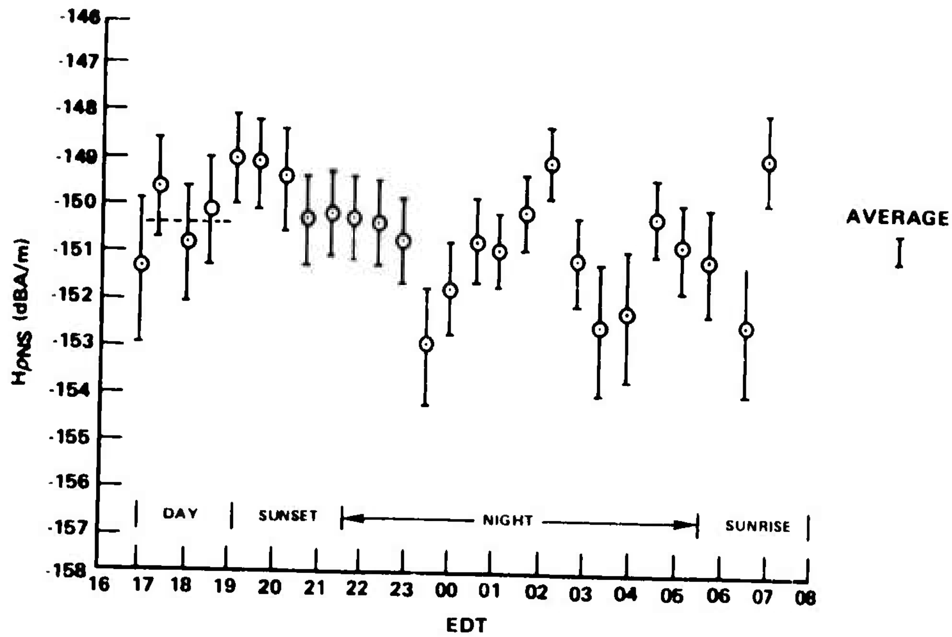

Figure 13. 28-29 March 42-Hz H_ρ Field Strengths Versus Local Time

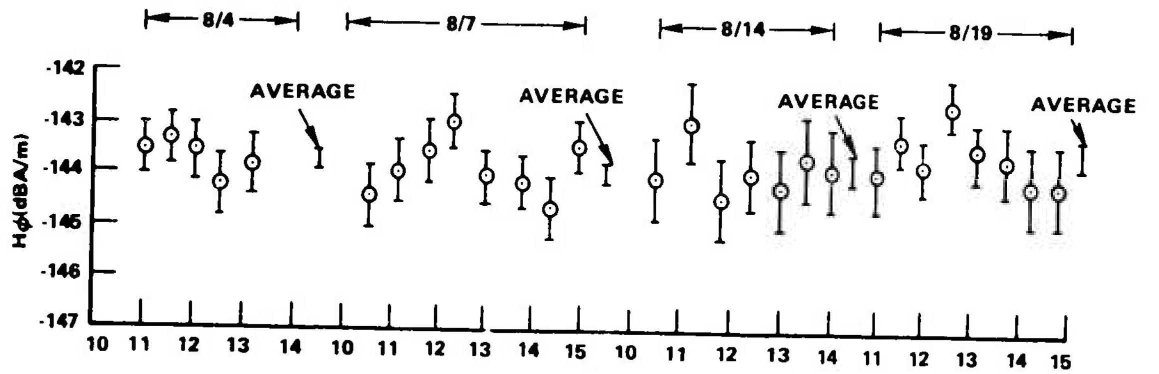

Figure 14. 4, 7, 14, and 19 August Daytime 76-Hz Field Strengths Versus Local Time

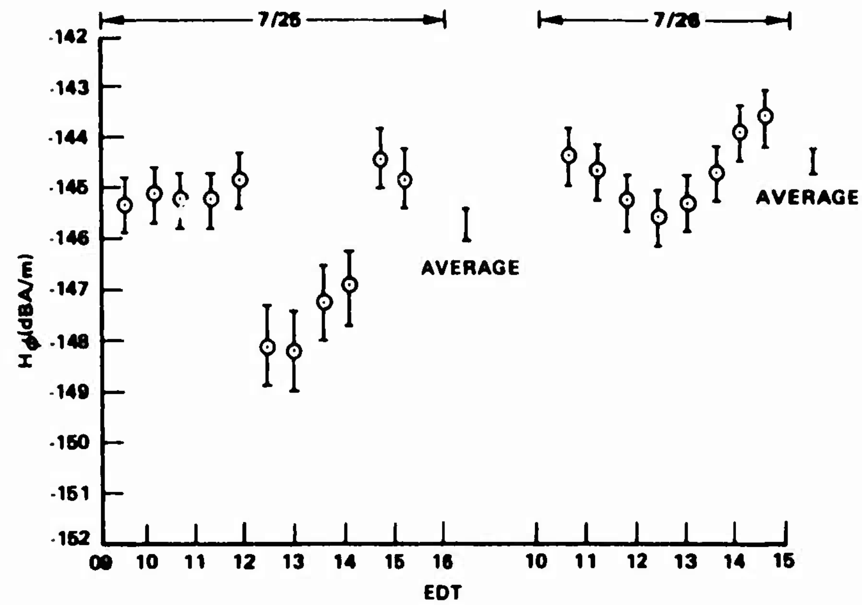

Figure 15. 25-26 July Daytime 76-Hz Field Strengths Versus Local Time

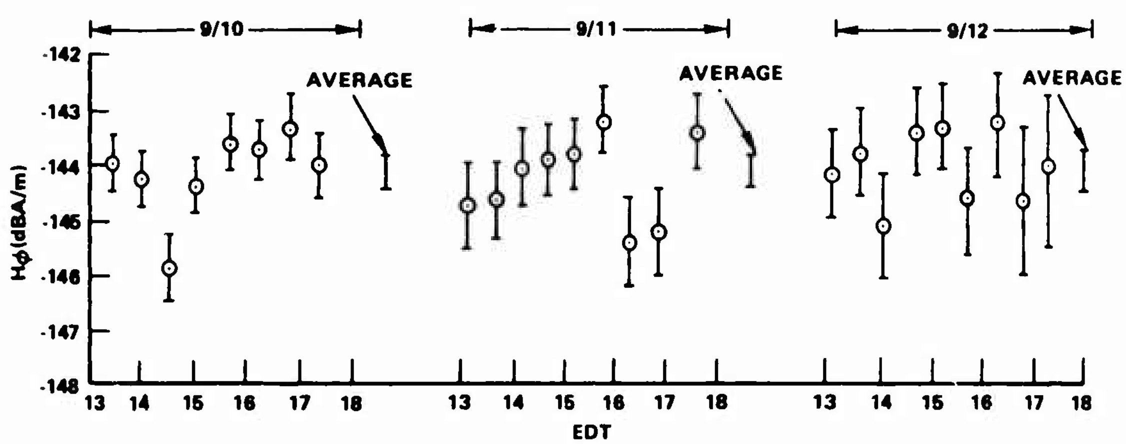

Figure 16. 9, 11, and 12 September Daytime 76-Hz Field Strengths Versus Local Time

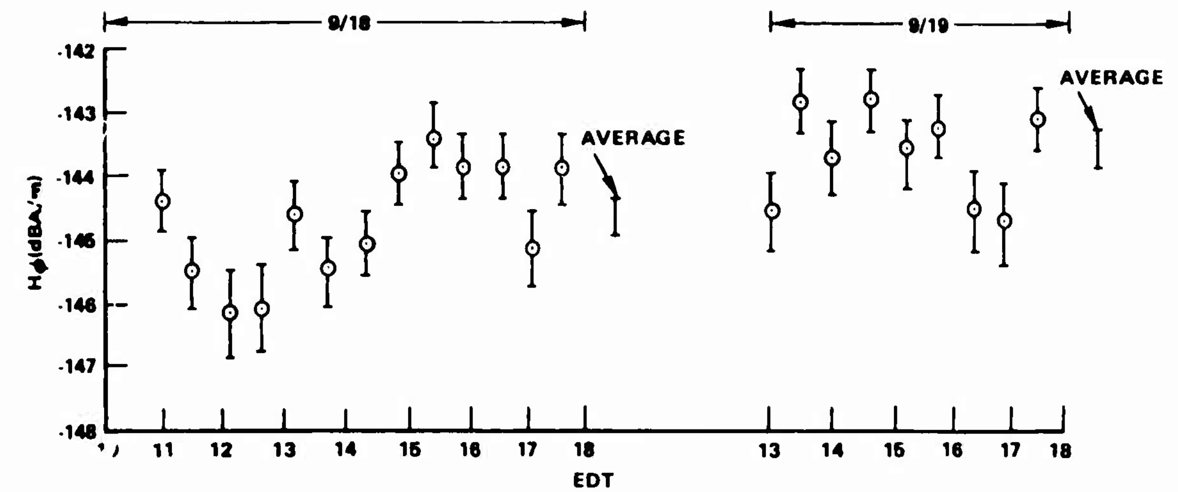

Figure 17. 18-19 September Daytime 76-Hz Field Strengths Versus Local Time

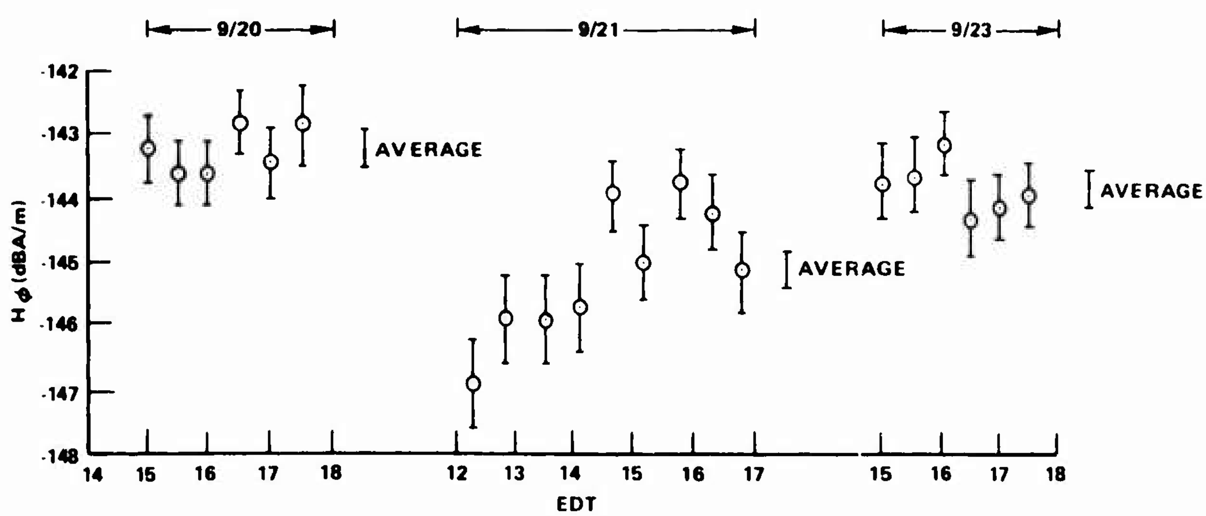

Figure 18. 20, 21, and 23 September Daytime 76-Hz Field Strengths Versus Local Time

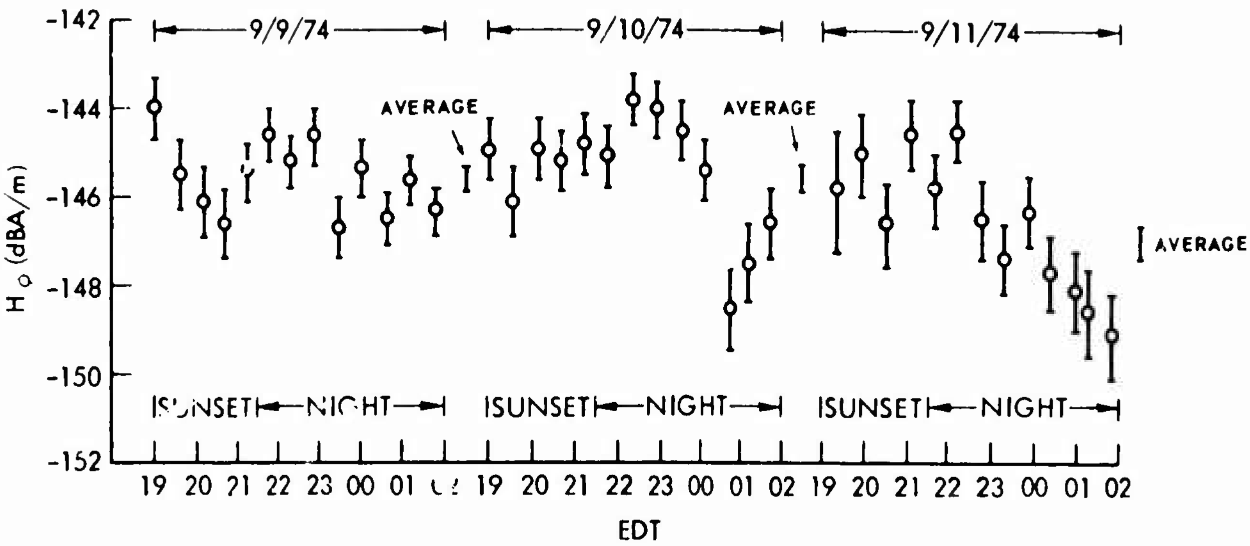

Figure 19. 9-11 September 76-Hz Field Strengths Versus Local Time

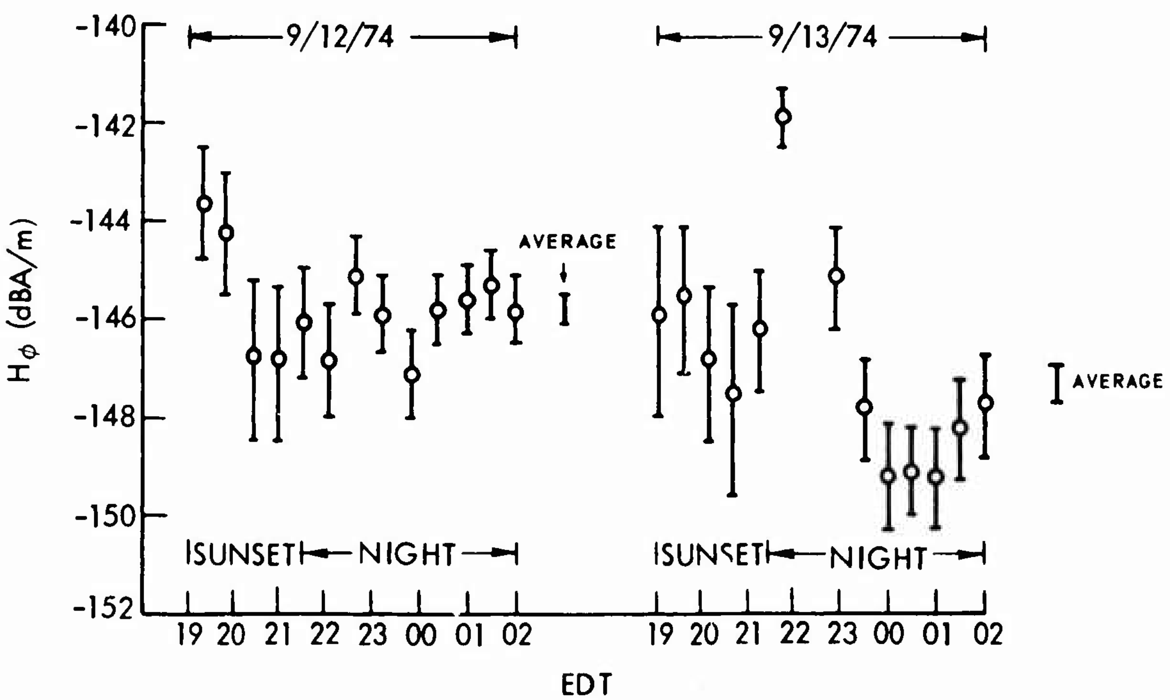

Figure 20. 12-13 September 76-Hz Field Strengths Versus Local Time

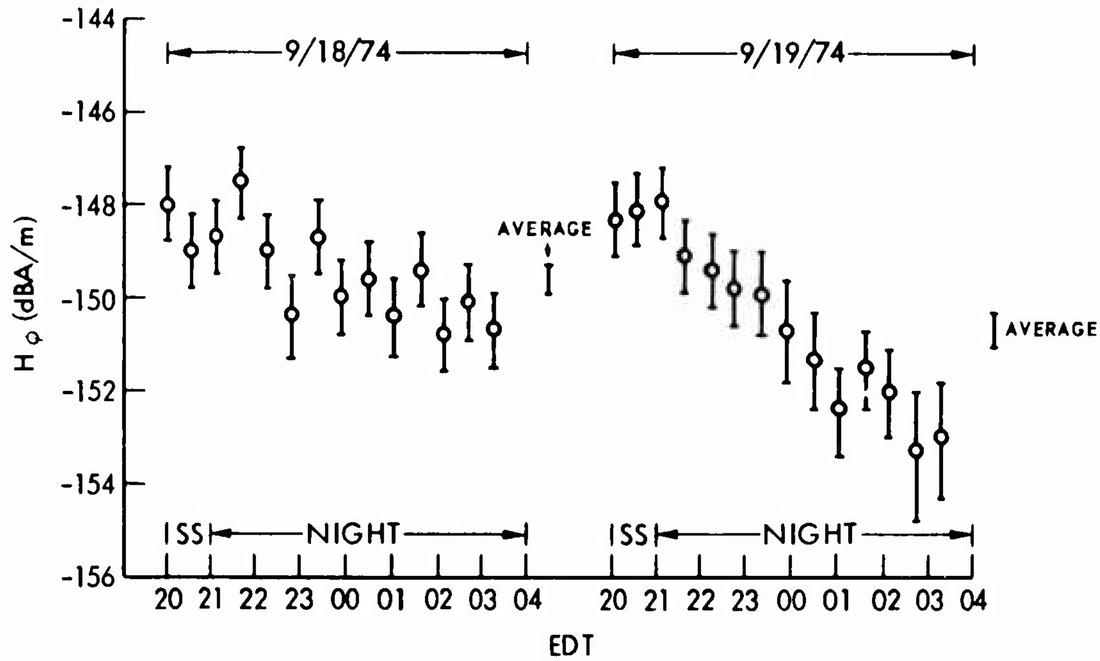

Figure 21. 18-19 September 42-Hz Field Strengths Versus Local Time

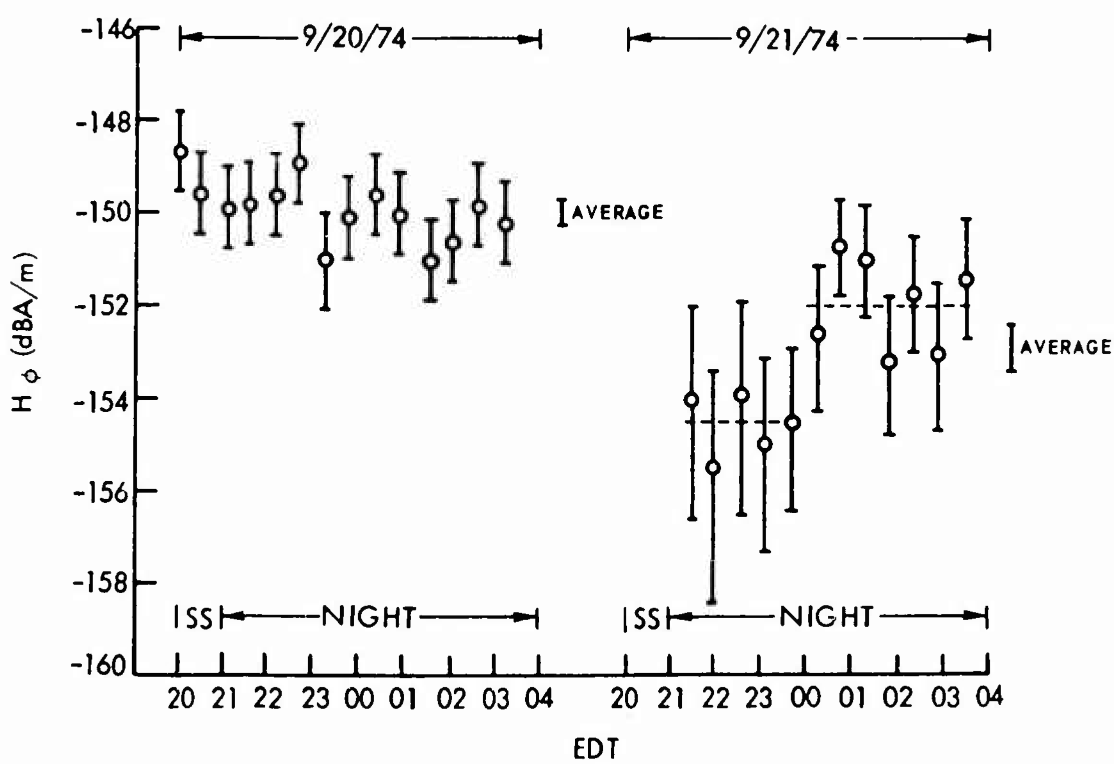

Figure 22. 20-21 September 42-Hz Field Strengths Versus Local Time

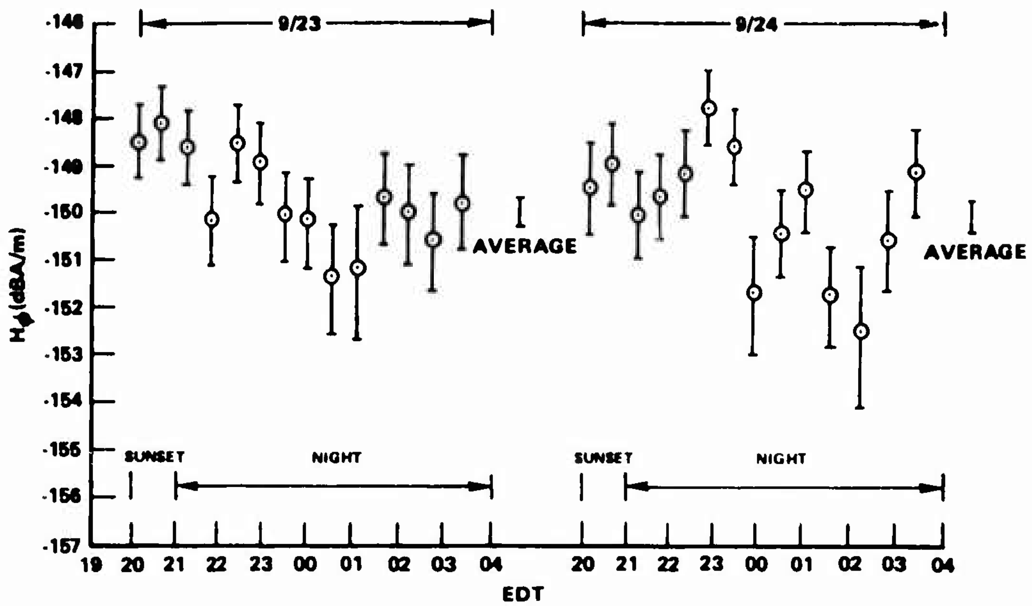

Figure 23. 23-24 September 42-Hz Field Strengths Versus Local Time

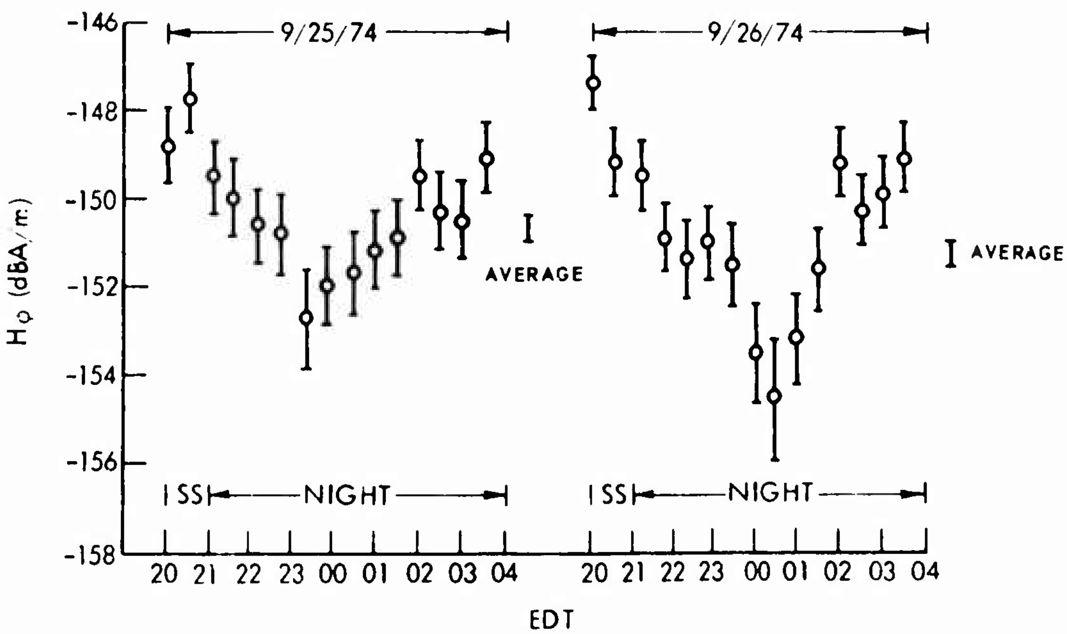

Figure 24. 25-26 September 42-Hz Field Strengths Versus Local Time

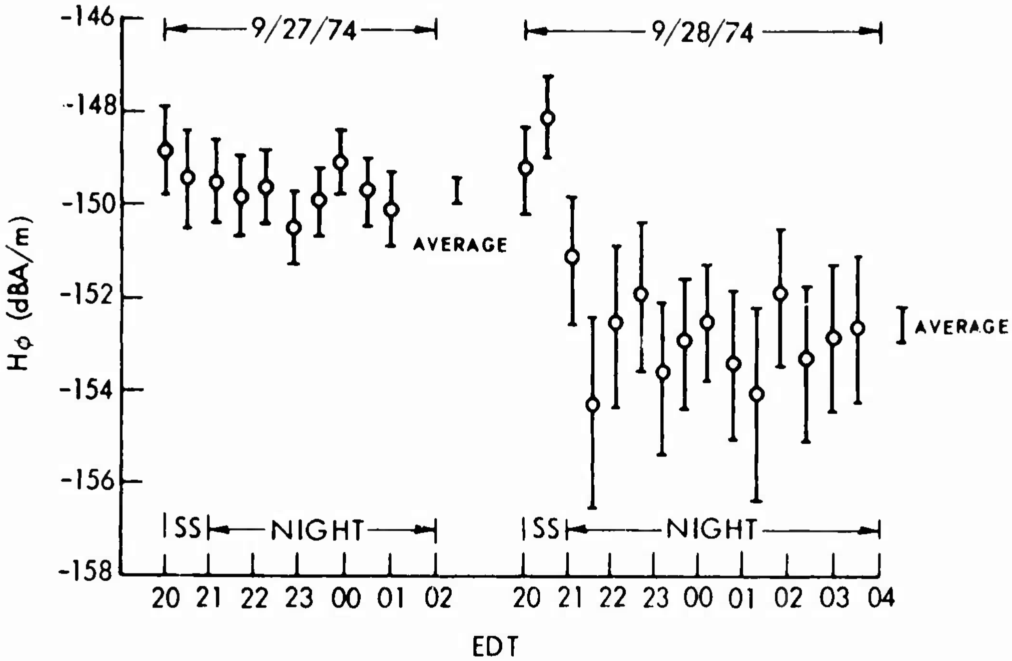

Figure 25. 27-28 September 42-Hz Field Strengths Versus Local Time

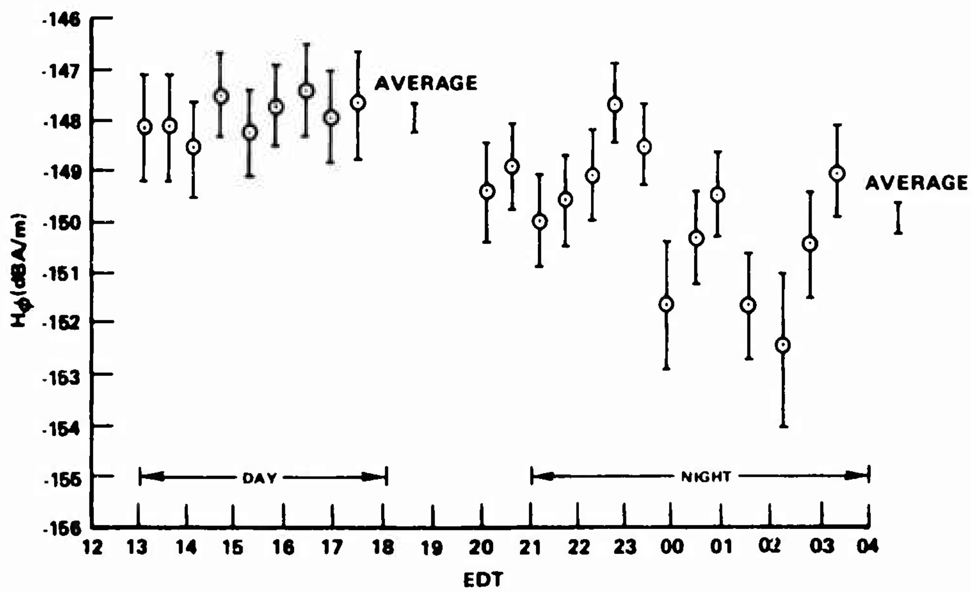

Figure 26. 24 September Daytime and Nighttime 42-Hz Field Strengths Versus Local Time

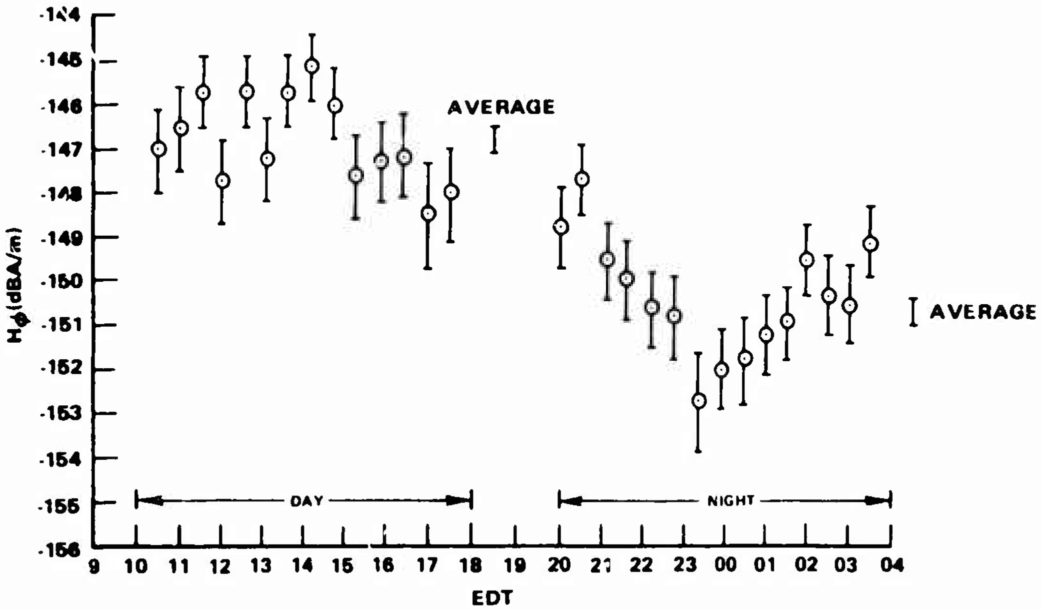

Figure 27. 25 September Daytime and Nighttime 42-Hz Field Strengths Versus Local Time

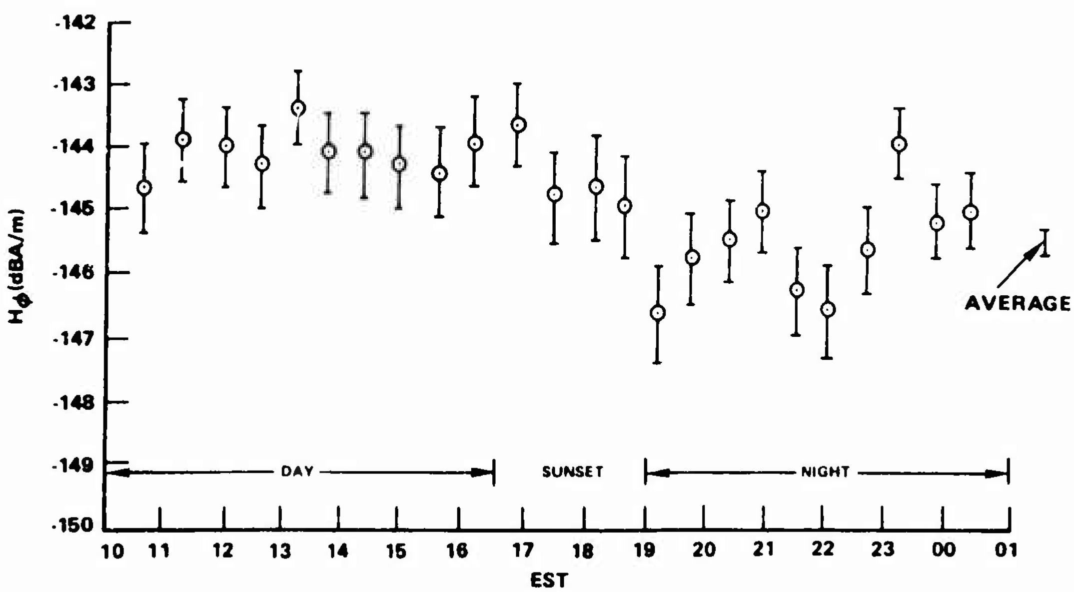

Figure 28. 28 October 76-Hz Field Strengths Versus Local Time

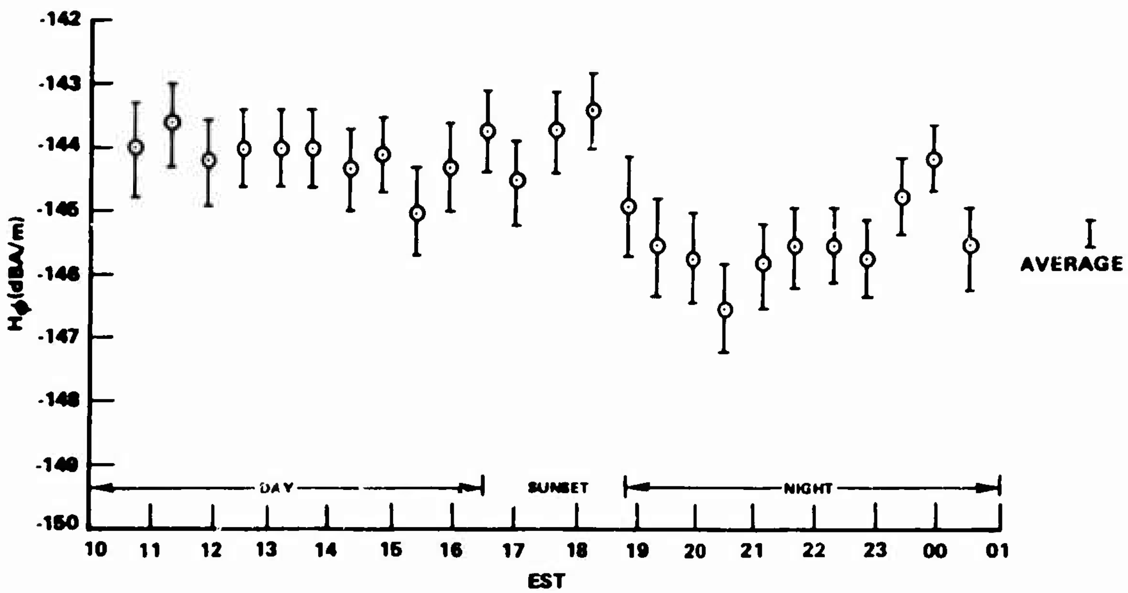

Figure 29. 29 October 76-Hz Field Strengths Versus Local Time

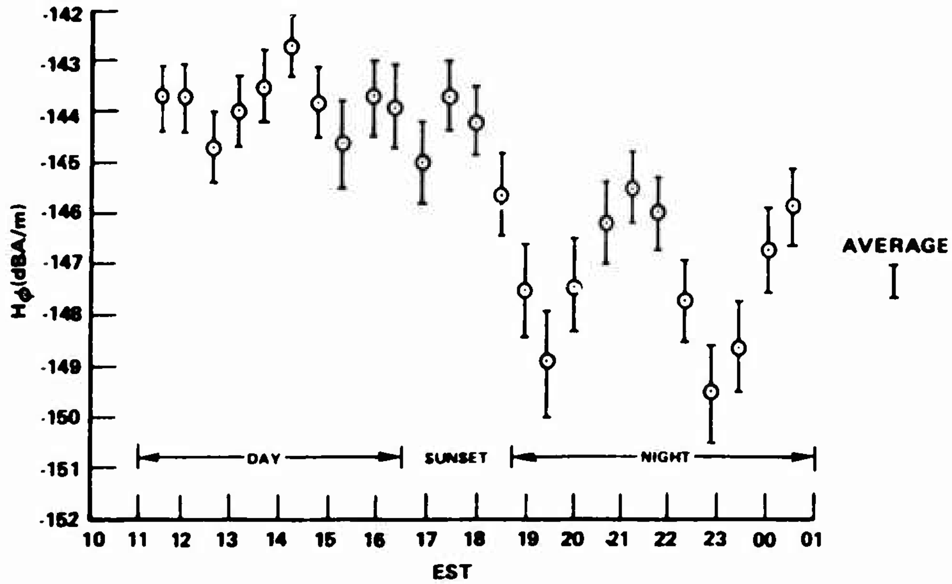

Figure 30. 30 October 76-Hz Field Strengths Versus Local Time

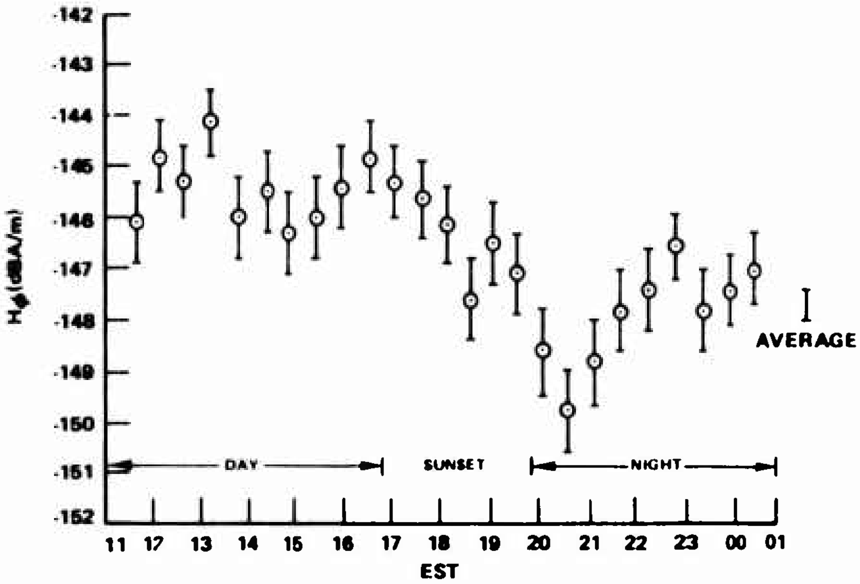

Figure 31. 31 October 76-Hz Field Strengths Versus Local Time

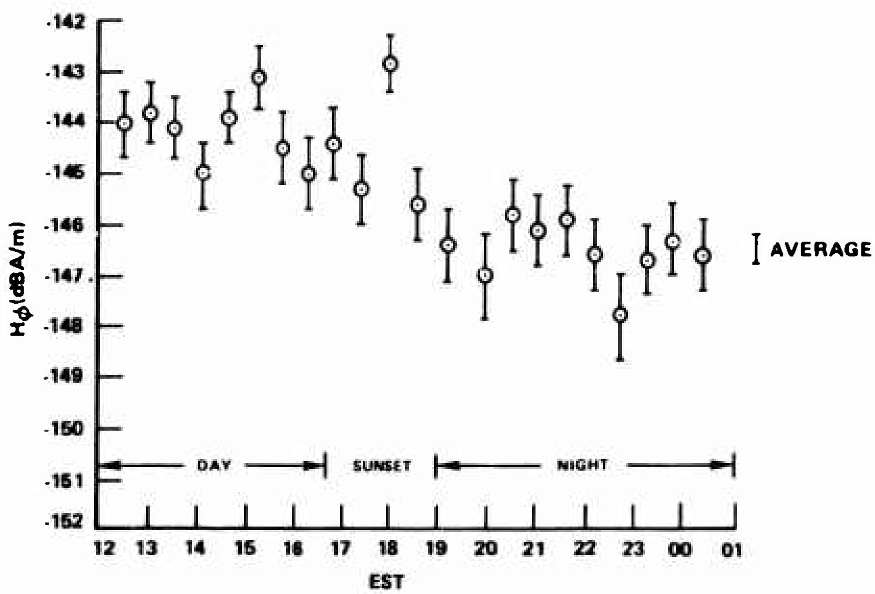

Figure 32. 1 November 76-Hz Field Strengths Versus Local Time

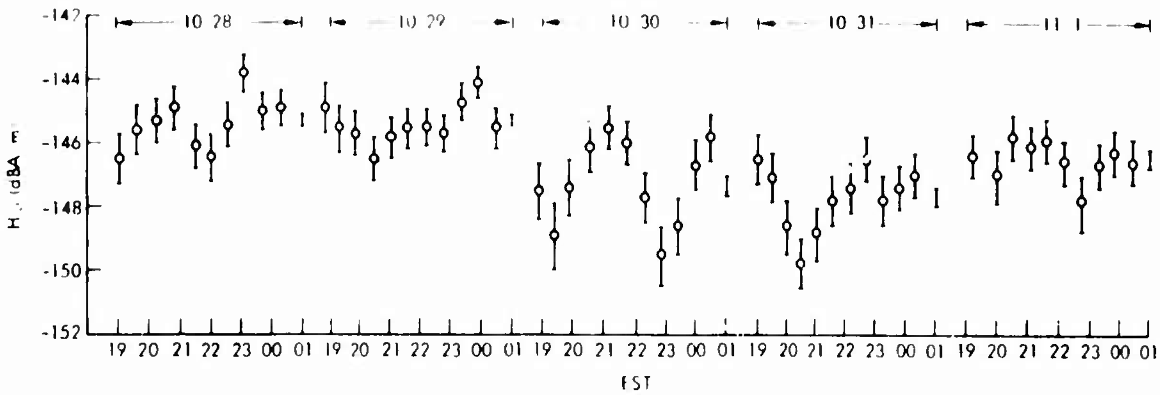

Figure 33. 28 October to 1 November Nighttime 76-Hz Field Strengths Versus Local Time

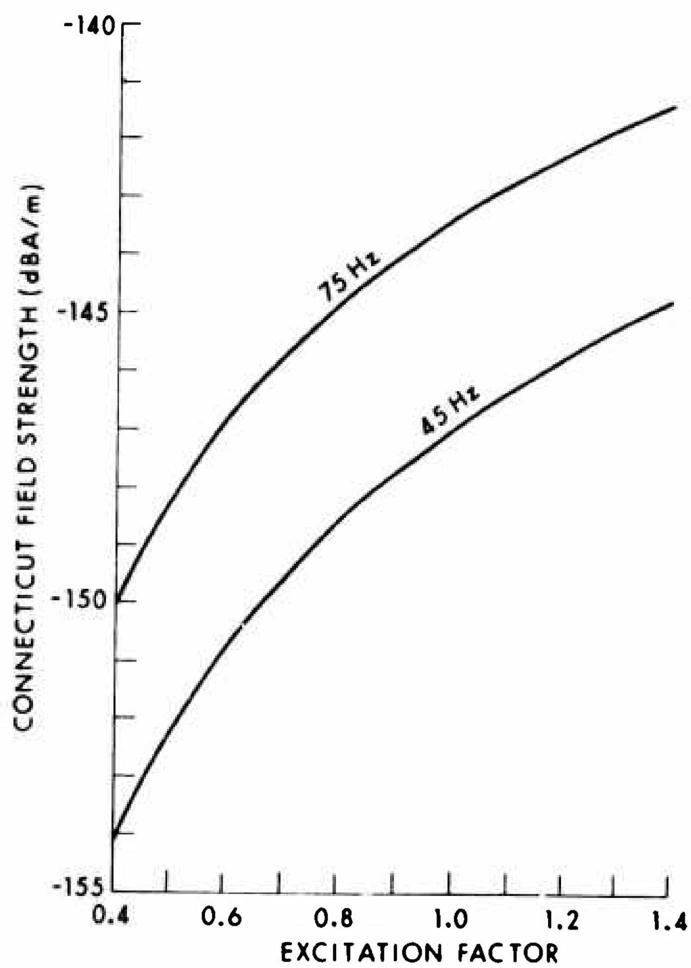

Figure 34. Connecticut Normalized Field Strengths Versus Excitation Factors